Research article

Visuotemporal cues clinically improved walking ability of ambulatory patients with spinal cord injury within 5 days

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Background/Objective: The human movement system uses a variety of inputs to produce movements. The concurrent use of external information, specifically visutemporal cues, while walking could promote the walking ability of ambulatory patients with spinal cord injury (SCI). This study explored the use of visutemporal cues in rehabilitation training by subjecting ambulatory individuals with SCI to walking training with or without visuotemporal cues and then assessing the effects on their functional ability.

Design: Quasi-experimental study.

Setting: A tertiary rehabilitation center.

Participants: Thirty-two participants were randomly assigned to the experimental or control groups using stage of injury, severity of SCI, and baseline walking ability as criteria for group arrangement (16 participants/group).

Interventions: The participants were trained to walk over level ground at their fastest safe speed with or without a visuotemporal cue, 30 minutes/day, for 5 consecutive days.

Outcome Measures: The 10-meter walk test, 6-minute walk test, timed up and go test, and five times sit-to-stand test.

Results: The participants demonstrated significant improvement in all functional tests after the 5 days of training ($P < 0.001$). In addition, the improvement in the group trained using the visuotemporal cue was significantly better than that trained without using the cue.

Conclusions: Most of these participants were at a chronic stage of SCI, so the findings supported a benefit for incorporating visuotemporal cues in rehabilitation practice, particularly today when the length of rehabilitation has dramatically decreased.

Keywords: Balance, Muscle strength, Physical therapy, Rehabilitation, Walking

Introduction

Spinal cord injury (SCI) likely distorts sensorimotor functions.[1] Nevertheless, conventional rehabilitation programs for these patients usually emphasize the impairments of motor functions and utilize compensatory strategies for the patients to achieve mobility.[2,3] In fact, sensory information is also important for the generation of motor activities.[4] Therefore, the somatosensory deterioration that occurs following SCI also crucially reduces the patient's walking ability.[3,4]

Several recent studies have attempted to provide optimal sensory inputs during walking training using a treadmill.[5–7] However, the deterioration of afferent pathways may have limited the ability of patients to utilize the information provided, so the effectiveness of the training has not been confirmed.

Bach-y-Rita and Kercel[8] reported that the human movement systems have a great capability to use alternative sources of inputs. Apart from the somatosensory

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system, the visual, auditory and vestibular systems also provide information necessary for walking.[9] This leads the current researchers to expect that the application of these alternative sources of inputs may promote rehabilitation outcomes for ambulatory patients with SCI.

Many studies have found that ambulatory participants with SCI can significantly increase their walking ability while using an external cue, particularly a visuotemporal cue (i.e. temporal information that the participant perceives visually, such as walking to a target within a time limit).[10–12] Such cue is regarded as non-specific because it does not specify any particular characteristics (i.e. increased step length or cadence) by which the participants are to increase their walking speed. Therefore, with this type of cue, individuals with SCI are able to reorganize their movements according to their own individual constraints, and they subsequently demonstrated better improvements in their walking ability than they do when given a specific cue (i.e. a visual or auditory cue).[10,11] However, the previous studies in this area were cross-sectional, so the benefit of using a visuotemporal cue in rehabilitation practice has not been directly confirmed.

Length of rehabilitation has decreased from 98 days in 1970s to 36 days in 2010 and length of re-admission takes approximately 10–15 days.[13,14] This evidence suggests the need for an effective rehabilitation program within a short period. This study investigated the effects of training participants to walk over level ground, with or without a visuotemporal cue on functional ability relating to walking in ambulatory participants with SCI. The researchers hypothesized that walking training with a visuotemporal cue would promote the utilization of participant's optimal mobility, subsequently they showed substantial improvement after a short period of training.

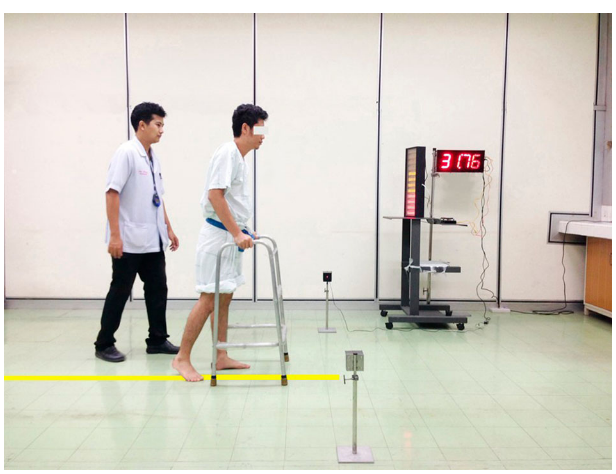

Figure 1 **Walking training with a visuotemporal cue.**

Methods

Participants

This was a quasi-experimental study in ambulatory participants with incomplete spinal cord injury (iSCI, American Spinal Injury Association [ASIA] Impairment Scale [AIS] classes C and D),[15] aged at least 18 years, from a major tertiary referral hospital in Thailand. The participants had an SCI from traumatic or non-traumatic causes and were at a subacute (post-injury time: PIT < 12 months) or chronic (PIT $\geq$ 12 months) stage of injury.[16] The training protocols were very demanding, so the study recruited participants who were able to walk independently with or without a walking device for at least 50 m (Functional Independence Measure Locomotor (FIM_L) scores 6-7).[17] The patients were excluded if they had any signs or symptoms that might affect ambulatory ability, such as severe spasticity of the lower extremity muscles (the modified Ashworth scale > 2),[18] pain in the musculoskeletal system with an intensity of pain more than 5 out of 10 on a numeric rating pain scale or deformities of the spine and lower extremities (i.e. scoliosis, kyphosis and equinovarus). A sample size calculation for two group comparisons (type II error) of a major variable (10-meter walk test) using data from a pilot study ($n = 5$) indicated that the study required 16 participants per group. Each participant signed a written informed consent document approved by the Ethics Committee for Human Research before participation in the study.

Protocol of the study

Participants were stratified to the experimental (walking training with a visuotemporal cue) or control (walking training without a visuotemporal cue) group using stage of injury (subacute or chronic stage), severity of injury (AIS class C or D), and baseline walking ability (ability to walk with or without a walking device) as the criteria for group arrangement.

On the first day, participants were interviewed and assessed for their baseline demographics, SCI characteristics (including causes, PIT, level and severity of injury as determined using the sensorimotor scores and the criteria from the standard ASIA protocol,[15] and the requirement of a walking device), and baseline functional ability. They then underwent the training program of their group on the subsequent days.

Walking training with a visuotemporal cue (experimental group)

The training program utilized a visuotemporal cue machine consisting of a countdown timer, electronic light bars, and laser sensors (Fig. 1). Prior to training, participants were assessed for their self-determined fastest safe walking speed over three trials. The average findings were used to set the appropriate time or temporal information for each participant (25% less than that required for the self-determined fastest speed).[10–12] Upon initiation of walking, participants were directed to the displayed light bars which indicated the time remaining on the countdown timer for the participants to complete the task. They were instructed to attempted to walk at their fastest safe speed to the end of the 10-meter walkway (or pass the laser sensors) before the final light bar turned off to stop the circuit (Fig. 1). If they could complete the task on time, no alarm sounded. If not was, the alarm went off.

Walking training without the visuotemporal cue (control group)

The difference in walking speeds among the participants was controlled as a confounding factor (i.e. different task demands) on the outcomes by training the participants in the control group to walk at their self-determined fastest safe speed along a 10-meter walkway without using any cues.

The participants were trained for approximately 30 minutes/day (excluding a period of rest), for five consecutive days. During participation, a walking device and rest breaks were allowed if needed. Participants fastened a lightweight safety belt around their waists and a physical therapist walked beside/accompanied them. Each participant still received routine treatments from unaffiliated rehabilitation professionals as needed during their participation in the study.

Outcome measures

Prior to and after completing the program (five training sessions), participants were assessed for their functional ability using the 10-meter walk test (10MWT), the 6-minute walk test (6MWT), the timed up and go test (TUG) and the five times sit-to-stand test (FTSST) in a random order.

Ten-meter walk test

The 10MWT reflects walking speed that is a vital determinant for overall quality of walking, ability to perform daily activities, community participation, and the advancement of ambulatory categories in ambulatory patients with SCI.[19–21] Participants were instructed to walk along a 10-meter walkway at a preferred and self-determined fastest speed for three trials/condition. The time was recorded over the 4 meters in the middle of the walkway in order to minimize acceleration and deceleration effects.[19,22]

6-minute walk test

The 6MWT reflects the global and integrated responses of the cardiopulmonary and muscular systems; thus the outcomes are associated with the functional status for daily activities.[17,23,24] Participants walked as far as possible in 6 minutes. They were informed about the time left, in one-minute increments, and rest breaks were allowed if needed. The time elapsed during the rest breaks so participants were encouraged to walk as soon as they could. The distance covered after 6 minutes was recorded.[23,24]

Timed up and go test

The TUG is associated with mobility and dynamic balance control while walking and changing postures.[19] Participants stood up from a standard armrest chair, walked at a self-determined fastest safe speed around a traffic cone located 3 meters away from the front edge of the chair, and returned to sit down on the chair.[19,22] The average time required to complete the test over the 3 trials was recorded.

Five times sit-to-stand test

The FTSST reflects functional lower extremity motor strength and the ability for balance control while changing from sitting to standing.[25,26] The subjects were instructed to stand up, with their hips and knees in full extension, and then to sit down; they were to repeat these actions five times, as quickly and safely as they could.[19,22] The average time required over three trials was used for data analyses.

Statistical analyses

Descriptive statistics were applied to explain characteristics of the participants and findings of the study. The dependent samples *t*-test was used to analyze the differences within the groups (before and after training). The independent samples *t*-test was utilized to compare the differences between the groups. The level of statistical significance was set at a P-value < 0.05.

Results

Thirty-six ambulatory participants with SCI agreed to participate in the study but four of them dropped-out due to having diarrhea ($n = 1$), having an operation ($n = 1$), having musculoskeletal pain ($n = 1$), and did not want to continue the program ($n = 1$). Therefore, 32 participants completed the study (16 participants/group and 13 males in each group). Most participants were at a chronic stage (14 participants/group; mean PIT = 43.5 ± 26.22 months) and had incomplete paraplegia and AIS D (13 participants/group). No significant differences were noted between the groups for

Table 1 Characteristics of the participants in the experimental and control groups

Variable	Experimental group ($n = 16$)	Control group ($n = 16$)	P value
Age (y)[a]	41.69 ± 10.90	45.63 ± 11.66	0.332
Weight (kg)[a]	61.61 ± 12.10	58.44 ± 11.18	0.447
Height (m)[a]	166.38 ± 6.73	164.56 ± 8.32	0.503
Body mass index (kg/m^2)[a]	22.11 ± 3.27	21.52 ± 3.33	0.617
Post injury time (months)[a]	35.00 ± 24.40	43.25 ± 29.95	0.400
Sex: males [n (%)][b]	13 (81)	13 (81)	1.000
Causes: traumatic SCI [n (%)][b]	3 (18)	7 (43)	0.252
Stage of injury: Chronic [n (%)][b]	14 (87)	14 (87)	1.000
Severity of injury: AIS D [n (%)][b]	13 (81)	13 (81)	1.000
Level of injury: incomplete paraplegia [n (%)][b]	11 (68)	12 (75)	1.000
Walking with a walking device: yes [n (%)][b,c]	8 (50)	8(50)	1.000

[a]The data are presented using mean ± SD and the findings between the groups were compared using the independent samples t-test.
[b]These variables are categorized as follows: Sex: male/female; Cause of injury: traumatic/non-traumatic SCI; Stage of injury: chronic/subacute; Severity of SCI: AIS C/AIS D; Level of injury: incomplete paraplegia/incomplete tetraplegia, Walking with a walking device: yes/no. The data between the groups were compared using the χ^2 test.
[c]In each group, 6 subjects used a standard walker, 1 subject walked with axillary crutches and 1 subject needed a single cane.
Abbreviation: AIS = American Spinal Injury Association (ASIA) Impairment Scale.

baseline demographics, SCI characteristics and sensorimotor scores ($P > 0.05$, Tables 1 and 2).

After training, participants in both groups showed significantly improved functional ability for all outcomes measured in this study ($P < 0.05$, Table 3); however, the magnitude of improvement was significantly greater in the experimental group than in the control group ($P < 0.05$, Table 3). Note also that participants in the experimental groups improved in their performance of the 10MWT and 6MWT to a much greater extent than the level of minimal detectable changes (MDC), and improved in the TUG and FTSST to levels greater than the standard errors of the measurements (SEM).

Discussion

The length of rehabilitation has been dramatically decreased and this trend is similar to that in our hospital, where the length of stay for an annual check-up normally takes 1–2 weeks. The data from a pilot study indicated that a 5-day training duration could possibly improve the functional ability of the participants. Therefore, the participants in the current study were trained for approximately 30 minutes/day, for five consecutive days. After training, both groups of participants with SCI showed significant improvement in their functional ability, and the functional improvement was clearly greater than the levels of MDC and SEM. No significant differences were observed in the baseline data between the groups (Tables 1 and 2), so the significant improvement after training suggests the benefit of training speed and external information provided. The participants in both groups were trained to walk at their fastest safe speed in order to minimize the difference due to training speeds (i.e. the preferred walking speed for the control group and fastest walking speed for the experimental group), so the observed difference clearly represent effects of the external information provided. Walking at their fastest speed facilitated the participants to modify their movement kinetic, kinematic,

Table 2 Sensorimotor scores

Variable		Experimental group ($n = 16$)	Control group ($n = 16$)	P-value[a]
Motor[b]	UEs (50)	46.44 ± 5.99	47.81 ± 4.85	0.481
	LEs (50)	36.38 ± 10.30	36.56 ± 9.69	0.958
Tactile[c]	UEs (32)	31.13 ± 6.24	31.00 ± 4.00	0.947
	LEs (36)	24.31 ± 8.12	24.56 ± 6.89	0.926
Proprioception[d]	UEs (12)	11.88 ± 0.50	12.00 ± 0.00	0.333
	LEs (12)	11.88 ± 0.50	12.00 ± 0.00	0.333

Note: The data are presented using mean ± SD.
[a]P-value from the independent samples *t*-test.
[b]Assessed for five key muscles of each upper extremity (UE) and lower extremity (LE) with the scores for each muscle range from 0–5. Thus the highest possible score is 50 (range 0–50) for the UEs and LEs (left and right sides).
[c]Assessed according to standard neurological classification of spinal cord injury; 2 = intact, 1 = impaired, 0 = loss. Thus the highest possible score for the UEs is 32 (range 0–32) and LEs is 36 (range 0–36).
[d]UE assessed at the shoulder, elbow, and wrist. LE assessed at the hip, knee, and ankle: 2 = intact, 1 = impaired, 0 = loss. Thus the highest possible score is 12 (range 0–12) for the UEs and LEs (left and right sides).

Table 3 Functional ability before and after the training period

Variable		Experimental group ($n = 16$)			Control group ($n = 16$)			Mean difference[a]		
		Pre-test	Post-test	P value[b]	Pre-test	Post-test	P value[b]	Experimental group	Control group	P value[c]
10-meter walk test	Preferred speed (meters/second)	0.60 ± 0.29	0.82 ± 0.40	<0.001*	0.67 ± 0.34	0.72 ± 0.39	0.027*	0.23 ± 0.17	0.05 ± 0.09	0.001*
10-meter walk test	Maximal speed (meters/second)	0.80 ± 0.42	1.17 ± 0.61	<0.001*	0.81 ± 0.42	0.92 ± 0.49	0.002*	0.37 ± 0.22	0.11 ± 0.12	<0.001*
6-minute walk test (meters)		185.09 ± 98.72	233.63 ± 118.89	<0.001*	194.56 ± 100.23	216.18 ± 113.24	0.009*	48.53 ± 42.46	21.62 ± 29.05	0.045*
Timed up and go test (seconds)		22.11 ± 14.72	16.15 ± 10.97	<0.001*	23.10 ± 18.02	20.89 ± 17.75	0.001*	5.96 ± 4.15	2.21 ± 2.18	0.004*
Five times sit-to-stand test (seconds)		12.14 ± 5.89	9.61 ± 5.17	<0.001*	12.19 ± 6.85	11.33 ± 6.56	0.045*	2.53 ± 1.68	0.86 ± 1.58	0.007*

Note: The data are presented using mean ± SD.
[a]The mean differences of the findings between the experimental and the control groups.
[b]P-value from the dependent samples *t*-test.
[c]P-value from the independent samples *t*-test.
*Indicates significant difference.

and spatiotemporal variables in order to generate their optimal walking ability.[27,28] Repetitive practice in a fastest walking manner imposed a high demand on many body systems involved in the task, specifically the muscular and cardiopulmonary systems, which subsequently improved the functional ability of the participants.[29,30]

While both groups demonstrated improvements, the significantly greater improvement seen in the participants in the experimental group may reflect the importance of the external information provided ($P < 0.05$, Table 3). Injury to the spinal cord distorted both the motor and the sensory functions of the participants (Table 2), preventing them from fully utilizing their internal reference of movement correction.[10,11] Gibson,[31] a pioneer who introduced an ecological approach for the relation between information and movement, indicated the importance of information or input as it specifies affordance or possibility for action. Dietz and Fouad[4] also emphasized the importance of afferent input on motor generation of patients with SCI. For these reasons, external information in the form of a visuotemporal cue was used in the present study to provide an alternative source of input for the participants. Upon initiation of walking, the gradual reduction of in the number of lit electronic light bars (Fig. 1) drew the attention of the participants and prompted them to use optimal movements to accomplish the task successfully within the time given. Repetitive practicing of the task may further activate the contribution of many body systems involved in walking to a greater extent than that when training without using the cue. Therefore, participants in the experimental group showed clinical improvement after a short period of training (30 minutes/day, 5 days in total) and the level of improvement was also significantly greater than in the control group (Table 3).

The improvement of participants in the experimental group was particularly evident with the 10MWT and 6MWT, which may reflect the influence of the specificity of training. Walking training helped the participants to discover, accommodate and exploit the task constraints in a manner that optimized their ability of movement control in relation to the task demands.[32] Therefore, the participants showed particular improvement on the variables directly related to walking ability (10MWT and 6MWT). The extent of improvement (0.23 m/s and 0.37m/s for the 10MWT at a preferred and self-determined fastest walking speed, respectively, and 48.53 meters for the 6MWT) was also greater than the MDC levels (0.13 m/s, 0.16 m/s and 45.8 meters for these 3 tests, respectively).[33] Although less marked, the levels of improvement for the TUG and FTSST (5.96 seconds and 2.53 seconds, respectively), which are indirectly related to walking ability, were greater than the SEM (3.9 seconds and 0.6 seconds for the TUG and FTSST, respectively).[33,34] Since most participants were at a chronic stage of SCI (n = 14, Table 1), the findings support a benefit for the incorporation of visuotemporal cues in rehabilitation practice, particularly since the length of rehabilitation has dramatically decreased in recent years.

Limitations

Some methodology considerations must be taken into account when interpreting the findings of this study. First, the visuotemporal cue has an accelerative effect and may draw the attention of the participants away from the walking task. The task is highly demanding, and the cue had a perceived benefit, but it may not be without risk (i.e. muscle soreness, fatigue, and risk of falling). Therefore, the training method may be suitable only for patients who have fairly good walking ability, which was a criterion used here for subject recruitment, and it may require the close supervision of a physical therapist. Second, the findings were measured immediately after training; thus learning effects or adaptive change within the sensorimotor systems could not be confirmed.[4] Third, participants in the control group were trained to walk at their fastest speed in order to minimize confounding factors that may occur due to different training speeds or demanding of the task. However, this training method differs from routine therapy, where physical therapists commonly train the patients to walk at their preferred walking speed. Thus, the findings cannot confirm the superiority of the training using a visuotemporal cue over a routine training program. Lastly, most participants had AIS D (n = 14 or 87% in each group, Table 1), which might facilitate improvement within a short training period. Further studies that include more participants with AIS C, measurements taken during a retention period, and comparison of a routine training program would further confirm the benefit of using visuotemporal cues in rehabilitation practice for these patients.

Conclusion

This study explored the effects of training participants to walk over level ground with or without a visuotemporal cue. After a training period consisting of 30-minute per day sessions for 5 consecutive days, the participants (mostly at a chronic stage of SCI) demonstrated significant improvement in their functional ability related to walking, with the greater improvement seen in participants who were trained using a visuotemporal cue. The findings confirm the benefit of using visuotemporal cues in rehabilitation practice for ambulatory patients with SCI, particularly given the dramatically curtailed length of rehabilitation treatments in recent years.

Disclaimer statements

Contributors NP: research plan, funding application, data collection, data analysis, and writing a manuscript. PA: research plan, development of the visuotemporal cue machine, writing a manuscript. TS: Development of the visuotemporal cue. PA: Data collection. SA: research plan and design, funding application, data collection, data analysis, and writing a manuscript.

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Conflicts of interest The authors declare no conflict of interest.

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